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USING DESIGN OF EXPERIMENTS AND RESPONSE SURFACE METHODOLOGY AS AN APPROACH TO UNDERSTAND AND OPTIMIZE OPERATIONAL AIR POWER

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14. ABSTRACT
The Air and Space Operations Center (AOC1) Command and Control data center node is the senior air power element on any battlefield. The AOC provides the Commander the capability to plan and execute theater-wide air and space operations. Two primary documents are created daily: the Air Tasking Order (ATO) and the Airspace Control Order (ACO). In any operation involving air power, usually a single commander is responsible for the air power force. In a theater-size military campaign, as many as 2500 people inside a Combined Air Operations Center (CAOC) move massive amounts of information across multiple networks. The CAOC provides the Commander the capability to direct and supervise activities of assigned or attached forces and monitor the actions of both enemy and friendly forces. The ATO and ACO promulgate his will throughout his command. Advanced optimization methods and statistical sampling techniques may significantly help quantitatively model and understand the interaction of combatants. This paper discusses using Response Surface Methodology (RSM) as an approach to understand and optimize operational air power and illustrates its application using an operational training system in conjunction with a fictitious force-on-force scenario.

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Abstract

The Air and Space Operations Center (AOC[1]) Command and Control data center node is the senior air power element on any battlefield. The AOC provides the Commander the capability to plan and execute theater-wide air and space operations. Two primary documents are created daily: the Air Tasking Order (ATO) and the Airspace Control Order (ACO).

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Advanced optimization methods and statistical sampling techniques may significantly help quantitatively model and understand the interaction of combatants. This paper discusses using Response Surface Methodology (RSM) as an approach to understand and optimize operational air power and illustrates its application using an operational training system in conjunction with a fictitious force-on-force scenario.

Key Words: Command and Control (C2), Response Surface Methodology (RSM), and Air Tasking Order (ATO)

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[1] For the purpose of this paper, the terms CAOC and AOC are synonymous

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Introduction

Humans are notoriously bad at visualizing any mathematical relationship beyond a direct or proportional linkage. Modern techniques help eliminate this condition. A plumb bob is an ancient tool used to create the Egyptian pyramids and, if one digs deep into most plumbers or carpenters' toolboxes, one can find that tool today, modified, but recognizable to any ancient Egyptian construction foreman. Command and Control (C2) has been around at least as long as plumb bobs, but using the same tools the ancients used does not guarantee success. When one thinks of the best "ancient" air power commanders it is easy to envision the "old-fashioned" fighter pilot: a natural leader and an intuitive tactician leading his command to victory.

During the Vietnam War, flying F-4 Phantoms or F-105 Thuds was dangerous work. Col. Robin Olds, the commander of the 8th Tactical Fighter Wing, came up with the qualitative strategy of luring North Vietnam's MiG-21s into battle with F-4s masquerading as the more vulnerable F-105s. The operation was named Bolo. It required a massive Air Force-wide effort to bring it to fruition. The battle was a total success. The Wright brothers advanced aviation not by improving the understanding of lift, but by mastering the interactions of control. Thirty-plus years later, we still qualitatively create air battle plans. The question that will be explored is "Can the science of control be used to help quantitatively understand and optimize the interaction of air combatants?" Sun Tzu said: "Know yourself and know your enemy and in a thousand battles you will be safe." Therefore, the goal of this paper is to explore whether the use of a strict quantitative technique has viability when used on a problem set as complex as combat air power.

What is an AOC?

Today, the Air and Space Operations Center (AOC[2]) Weapon System, AN/USQ-163 Falconer, military C2 data center node is the senior element of the Theater Air Control System on the battlefield. (Kometer, 2005) The primary function of the divisions of the AOC is to produce and execute an Air Tasking Order (ATO) and associated documents like the Airspace Control Order (ACO). The Air Force has fielded five permanent Falconers worldwide to meet continuing air power challenges. In any operation involving air power, a single commander is designated the responsible member for all air power forces assigned and attached. In a theater-size military campaign, as many as 2500 people inside the Combined AOC (CAOC) move massive amounts of information across multiple communication networks of various security levels. The CAOC provides the Commander the capability to direct the activities of assigned, supporting, or attached forces and monitor the actions of both enemy and friendly forces. Walking into any of the five worldwide CAOCs for the first time is an extraordinary experience. It is just what you expect of the nerve center of the most powerful Air Force on earth. Huge projection screens show the exact location of every military aircraft flying over the theater of operations; CNN, Fox, and other news organizations; and other situation displays. Rows of professional warriors operate computer screens and banks of telephones communicating worldwide while absorbing vast amounts of information from organizations across the planet. The Combined Force Air Component Commander (CFACC) sits in a room with his key staff. Video and data screens show live feeds from various sensors over the battlefield. Chat rooms on computer screens exchange information across all security level. An interesting question to be asked is whether these modern

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[2] For the purpose of this paper, Joint Force Air Component Commander (JFACC) and Combined Force Air Component Commander (CFACC) are synonymous

warriors' efforts can be changed from their qualitative approach and augmented with quantitative tools?

What is an ATO?

With all this command and control technology, my assertion is the most critical weapon of war is the human mind; the rest can be viewed as just tools. To understand complex processes such as air war, it may sometimes be best to combine all the variables into simplified models that can represent their interactions. The ATO and ACO are the documents used to disseminate the commander's plan for all combat air power forces. For an aviator, these are the only two documents provided by higher headquarters to answer the question, "What am I doing tomorrow?" The ATO and ACO are United States Message Text Format (USMTF) military messages that combine to provide a written description of the next day's air battle plan. Based on experience, the goal of building the ATO/ACO is to provide a single source document for everything that flies and provide awareness to other combatants in the Area of Responsibility (AOR), and anything that uses airspace within the AOR, in the next 24-hour period. These documents may be hundreds of pages of computer printout traditionally approved and transmitted 12 hours before execution.

There is a 12-hour period between the ATO being published and start of the battle plan. As soon as the tactical units receive the ATO/ACO, they begin detailed planning to create mission-planning folders for the aircrews. At the same time, maintenance also receives the ATO, builds the ordnance required, and starts loading the aircraft. The time between D-12 and D+0 is critical for these functions to accrue. At D+0 hours, execution of the ATO and implementation of the ACO occurs. The CAOC makes adjustments as the battle unfolds. These adjustments can be minor, such as approving a Time On Target (TOT) change by 15 minutes due to a wing

maintenance delay or so major that every line of the ATO becomes invalid and must be recreated. It is very hard for any Commander to visualize and optimize the interactions of all these moving parts.

Understanding Interactions: An Approach

The AOC is an organization, which is on its best days, is qualitatively efficient and accurate in its planning and execution. A qualitative approach augmented with quantitative techniques has the potential to improve the efficiency, accuracy, and specificity required in the operational planning and tactical delivery of air power. If one considers an Air Battle Plan as a large-scale black box of interactions it is easier to comprehend than all the individual moving actions. Tanker and other support aircraft become binding agents and weapons and enemy actions become catalysts of change. From this perspective, system parameter design techniques can be applied to quantitatively optimize interactions. System design is the process of applying knowledge to produce a basic functional design and, in this case, it would produce a qualitatively created ATO. The original ATO created by the AOC would define the attributes of the Air Battle Plan undergoing analysis. Assuming zero transportation time, the maximum analysis time would only be 12 hours. The qualitative initial design may be functional, but it is far from optimum in terms of second and third order interactions not easily visualized by experts creating it. The objective in parameter design is to identify the settings that optimize the desired performance characteristic (Phadke, 1989; Kackar, 1985). We often see Subject Matter Experts (SMEs) in the AOC working qualitatively until the plan "looks good" or they run out of time to do anything different. Experimenting with the design variables one at a time or by trial and error is a common approach to optimization (Phadke, 1989; Bendel, 1988). However, this approach can lead to a very long and expensive time span for completing the design. Furthermore, using the one

variable at a time approach, parameter interactions that may affect the optimum results cannot be identified (Gunter, 1990). The result in most cases is a product design (ATO) that may be far from the most advantageous. To determine the optimum conditions, a "full factorial" approach in which all possible combinations of parameter values are tried may be necessary. A full factorial approach quickly grows exponentially large,e.g., 13 factors at three levels would require studying 1,594,323 (3^{13}) experiments! To validate that a quantitative approach is possible to use to study improving an ATO, the factors are limited to four different type of aircraft assigned to various units at two different levels (full up and 30% reduced). It is further assumed the aircraft under study would have forward firing missile ordnance, require air refueling, go well beyond the forward edge of the battle area, or be a purely defensive air-to-air aircraft. The model used to simulate combat was an operational training tool named Command and Control Weapon System Part Task Trainer (C2WSPTT) (pronounced Chew-spit) used to fly out ATOs and simulate combat to an AOC training audience. C2WSPTT was the only model readily available to accomplish the necessary data runs. To make the unclassified scenario robust, we used 631 pieces of airspace, 550 blue (friendly) missions, and 197 red (enemy) missions. Consequently, if the ATO were run, it would complete 24 hours of missions in approximately 25 minutes of actual time. Sixteen experimental test runs would require a little over half of the 12 hours traditionally available. The reported speed is 65 times normal. When a real ATO is flown with all the factors associated with combat, the maximum speed of C2WSPTT is about 2.5 times normal operating on commercially available computer platforms. To ensure no aircraft was shot down from ground by surface to air missiles (SAMs), we turned them all (both red and blue) off, as the SAM factor would have overwhelmed the number of red aircraft destroyed. Normally, Intelligence will brief two scenarios for enemy actions, “most likely” and “worst case.” We were

only able to create one red ATO; therefore, it was flown against the “most likely” scenario only. Without knowing the conceptual foundational of C2WSPTT, potential stochastic variation in ATO fly out was minimized by elimination the same mission numbers in the ATO whenever the 30% reduction was required.

With the parameters of the simulation in place, we are ready to explore if an engineering quantitative method can be used to optimize an ATO. Response surface methodology (RSM) is a set of mathematical and statistical techniques for analysis designed to create a mathematical model to efficiently explore any variable. In the case of combat air power, the variables were number of blue aircraft lost (minimized) and number of red aircraft destroyed (maximized). Using experimental design methods, RSM seeks to relate a *response* or *output* variable to the values of a number of *predictors* or *input* variables that affect it (Box & Draper, 1987). Response can be defined as the performance or quality characteristic of interest (e.g., yield, weight, number of aircraft). These techniques, introduced by Box and Wilson (Myers, 1971) and later amplified by others, consist of designing the experiment and the subsequent analysis of experimental data (Cornell, 1990). RSM can lead to a rapid and accurate exploration of the ATO and to estimated optimum conditions within our limited time and experimental data.

STEPS INVOLVED IN PARAMETER DESIGN

There are six steps in a typical parameter design. These are;

A. Identify the characteristic to be observed and the functions to be optimized,
B. Identify the factors and levels,
C. Define most likely interactions between parameters (factors),
D. Create the matrix experiment required and define the data analysis plan,
E. Conduct the experiments,
F. Analyze the data to determine optimum levels of factors and verify.

The first four steps are required for planning the experiment. In the fifth step, the experiments are conducted. In this case, the operational training system is run. In Step Six, experimental results are analyzed, optimum levels determined, and confirmation experiment is conducted to verify results if an experiential run does not contain the optimization of the expected factors.

The details of these six steps are described below.

A. Identify the characteristic to be observed and the functions to be optimized

Primary functions for optimization are the number of blue aircraft lost and number of red aircraft destroyed. The characteristic to be observed and Y function is number of aircraft. The objective is to determine the optimum combinations of design parameter values to minimize the number of blue aircraft lost and, at the same time, maximize the number of red aircraft destroyed. We will be emulating, as best we can quantitatively, Operation Bolo.

B. Identify the factors and levels

In factor design, two or three levels or settings are selected for each parameter/factor (Kackar, 1985). The *level* of a parameter refers to how many test values of the parameter are to be analyzed over the feasible range. In this study, two levels of each parameter were studied: a high (level-1) and a low (level-2) value (Unal & Stanley & Joyner, 1993). Factors and levels of the four variables selected for study are in Table 1.

Factors		Level-1	Level -2
1	F18 Units	100%	70%
2	F16 Units	100%	70%
3	F15C Units	100%	70%
4	F15E Units	100%	70%

Table 1: Factors and levels.

The levels represent an outcome that a commander would require to be studied such that, for various combinations of parameters, it would remain reasonable.

C. Define most likely interactions between these parameters (factors)

Varying several factors simultaneously may have interactive effects on our "black box" that affect the optimum solution. When the effect of one parameter depends on the level of another, an interaction is said to exist (Kackar, 1985). It is important to understand the interactions to find optimum minimal and maximal relations. For this operational air power problem, it was difficult to estimate which pairs of parameters will have strongest interactions. Therefore, all interactions that may be significant were to be investigated.

D. Design the matrix experiment required and the define data analysis plan.

Using Yates algorithm to code the experiments, one would expect the main functions to react as depicted in Table 2 and the interactions functions as in Table 3. Instead of writing each number in detail Yates algorithm allows a +1 to indicate high level and a – 1 to indicate a low level. The algorithm requires starting with -1 and them alternating to a plus one. Each additional column of factors requires alternating signs in pairs.

Experiment Number	A	B	C	D
1	-1	-1	-1	-1
2	+1	-1	-1	-1
3	-1	+1	-1	-1
4	+1	+1	-1	-1
5	-1	-1	+1	-1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	-1
9	-1	-1	-1	+1
10	+1	-1	-1	+1
11	-1	+1	-1	+1
12	+1	+1	-1	+1
13	-1	-1	+1	+1
14	+1	-1	+1	+1
15	-1	+1	+1	+1
16	+1	+1	+1	+1

Table 2: Main Effects.

Experiment Number	AB	AC	AD	BC	BD	CD
1	+1	+1	+1	+1	+1	+1
2	-1	-1	-1	+1	+1	+1
3	-1	+1	+1	-1	-1	+1
4	+1	-1	-1	-1	-1	+1
5	+1	-1	+1	-1	+1	-1
6	-1	+1	-1	-1	+1	-1
7	-1	-1	+1	+1	-1	-1
8	+1	+1	-1	+1	-1	-1
9	+1	+1	-1	+1	-1	-1
10	-1	-1	+1	+1	-1	-1
11	-1	+1	-1	-1	+1	-1
12	+1	-1	+1	-1	+1	-1
13	+1	-1	-1	-1	-1	+1
14	-1	+1	+1	-1	-1	+1
15	-1	-1	-1	+1	+1	+1
16	+1	+1	+1	+1	+1	+1

Table 3: Interaction Effects.

The Data Analysis Plan will use a combination of response tables and regression analysis to determine the interactions of the combatants.

E. Conduct the experiments

The results of the 16 experiments are presented in Table 4 and Table 5. Complete records of the experiments are available in Appendix A.

Expt Number	A	B	C	D	AB	AC	AD	BC	BD	CD	Blue Lost **Y**
1	-1	-1	-1	-1	1	1	1	1	1	1	36
2	1	-1	-1	-1	-1	-1	-1	1	1	1	39
3	-1	1	-1	-1	-1	1	1	-1	-1	1	35
4	1	1	-1	-1	1	-1	-1	-1	-1	1	35
5	-1	-1	1	-1	1	-1	1	-1	1	-1	39

Expt Number	A	B	C	D	AB	AC	AD	BC	BD	CD	Blue Lost **Y**
6	1	-1	1	-1	-1	1	-1	-1	1	-1	34
7	-1	1	1	-1	-1	-1	1	1	-1	-1	34
8	1	1	1	-1	1	1	-1	1	-1	-1	33
9	-1	-1	-1	1	1	1	-1	1	-1	-1	34
10	1	-1	-1	1	-1	-1	1	1	-1	-1	35
11	-1	1	-1	1	-1	1	-1	-1	1	-1	37
12	1	1	-1	1	1	-1	1	-1	1	-1	33
13	-1	-1	1	1	1	-1	-1	-1	-1	1	33
14	1	-1	1	1	-1	1	1	-1	-1	1	33
15	-1	1	1	1	-1	-1	-1	1	1	1	35
16	1	1	1	1	1	1	1	1	1	1	39

Table 4: Blue Aircraft Lost

Expt Number	A	B	C	D	AB	AC	AD	BC	BD	CD	Red Lost **Y**
1	-1	-1	-1	-1	1	1	1	1	1	1	56
2	1	-1	-1	-1	-1	-1	-1	1	1	1	56
3	-1	1	-1	-1	-1	1	1	-1	-1	1	54
4	1	1	-1	-1	1	-1	-1	-1	-1	1	54
5	-1	-1	1	-1	1	-1	1	-1	1	-1	56
6	1	-1	1	-1	-1	1	-1	-1	1	-1	56
7	-1	1	1	-1	-1	-1	1	1	-1	-1	53
8	1	1	1	-1	1	1	-1	1	-1	-1	52
9	-1	-1	-1	1	1	1	-1	1	-1	-1	56
10	1	-1	-1	1	-1	-1	1	1	-1	-1	57
11	-1	1	-1	1	-1	1	-1	-1	1	-1	53
12	1	1	-1	1	1	-1	1	-1	1	-1	55
13	-1	-1	1	1	1	-1	-1	-1	-1	1	55
14	1	-1	1	1	-1	1	1	-1	-1	1	55
15	-1	1	1	1	-1	-1	-1	1	1	1	53
16	1	1	1	1	1	1	1	1	1	1	55

Table 5: Red Aircraft Destroyed

F. Analyze the data to determine optimum levels of factors and verify.

Since the experimental design is orthogonal, it is possible to separate the effect of each parameter (Bryne & Taguchi, 1986). The average weights for each factor (as explained below) were calculated and are provided in the following responses tables.

Factor	A	B	C	D
Level-1	35.125	35.125	35	34.875
Level-2	35.375	35.375	35.5	35.625
Sensitivity	-0.25	-0.25	-0.5	-0.75

Table 6: Blue Aircraft Lost Sensitivity

Factor	A	B	C	D
Level-1	55	53.625	54.375	54.875
Level-2	54.5	55.875	55.125	54.625
Sensitivity	0.5	-2.25	-0.75	0.25

Table 7: Red Aircraft Destroyed Sensitivity

The response tables show the loss of aircraft effects of the factors at each level. These are separate effects of each factor commonly called main effects (Phadke, 1989). The average aircraft lost/destroyed in the response table are calculated by taking the average from Table 4 or 5 for a factor at a given level every time it was used. As an example, the factor "A" (F18s) was at level two in experiments 1, 3, 5, 7, 9, 11, 13, and 15. The average of blue aircraft lost is shown in the response in Table 6 under "A" at level-2. This procedure is repeated and the response table is completed for all factors at each level. The number of aircraft lost/destroyed effect sensitivity is computed by taking the difference between the largest and smallest number for a given factor. The response table for blue aircraft lost reveals that the number of F15E shows the greatest sensitivity, meaning that the largest effect on blue aircraft lost is realized by varying this factor. The response table for our maximization problem of Red aircraft destroyed reveals that number of F16, Factor "B," shows the greatest sensitivity, meaning that the largest effect on Red Aircraft Destroyed is realized by varying this factor. Similarly, blue aircraft lost factor "A" (F-18s) and

factor “B,” F-16, shows the least sensitivity. Additionally, Factor “A” (F-18s) show the least sensitivity to Red aircraft destroyed. The average aircraft lost/destroyed for Blue Factor “A” and Red Factor “B” are also graphed.

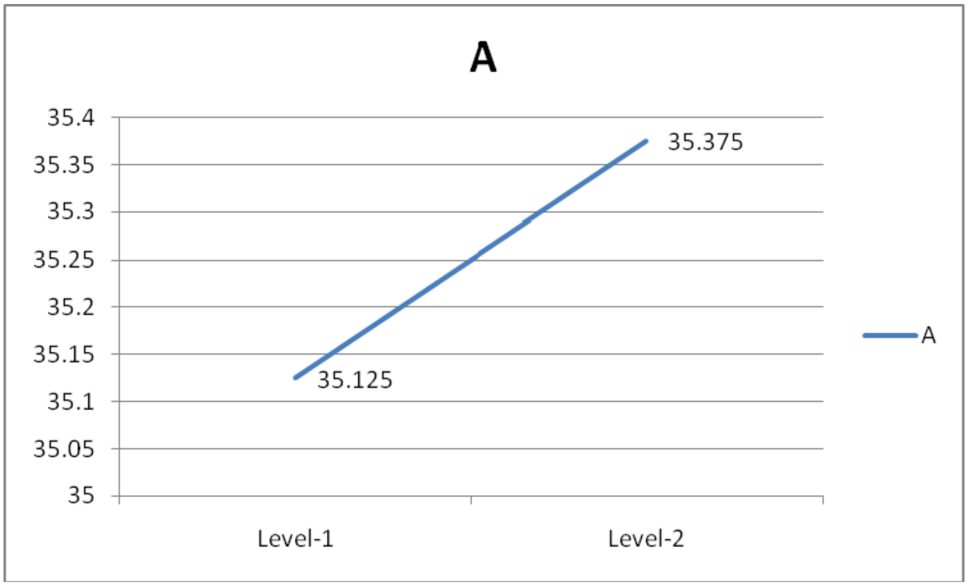

Figure 1: F18 Sensitivity

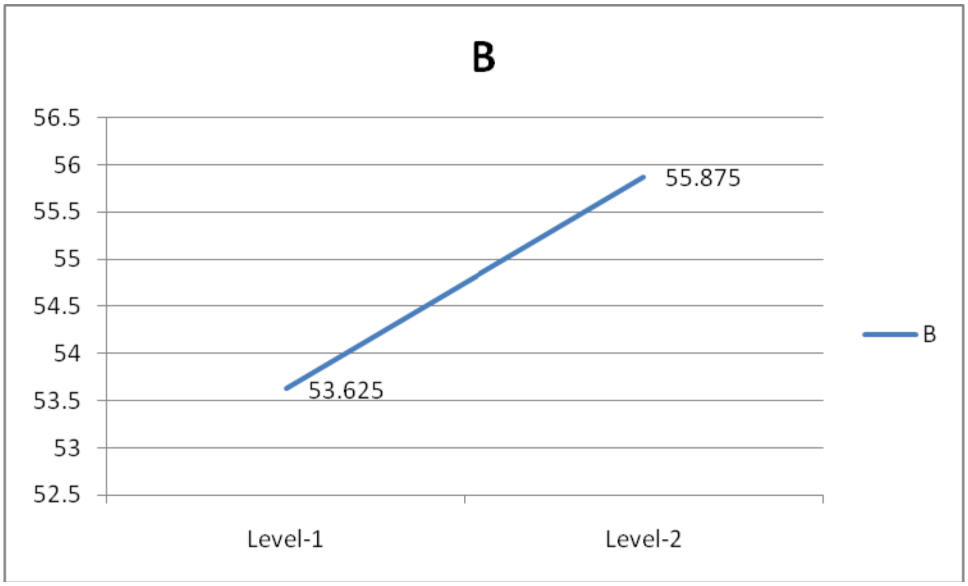

Figure 2: F16 Sensitivity

To estimate factor interaction effects, a two-way interaction response table is prepared from the observed data. Table 7 and Figure 3 display the interaction response tables for Blue Aircraft Lost B and D interactions.

	B_{-1}	B_{+1}
D-1	35.5	35.38
D+1	35.38	35

Table 7**:** Blue Aircraft Lost interaction of B and D

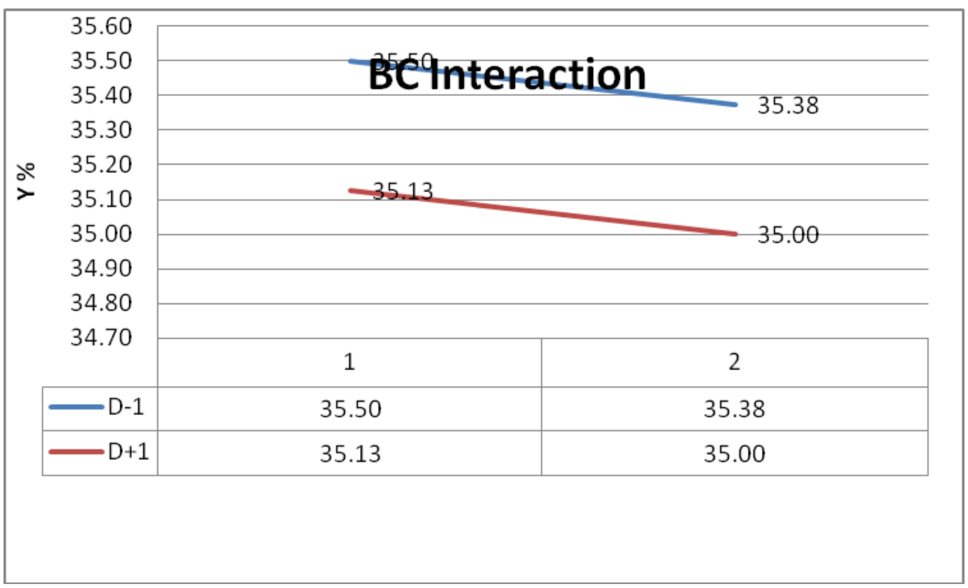

Figure 3. Factor D and B plotted

Estimating an interaction means determining the non-parallelism of parameter effects (Phadke, 1989). Thus, if the lines on the interaction plots are not parallel, interactions occur and if the lines cross, strong interactions occur between parameters (Phadke, 1989). An examination of Figure 3 yields no interaction between F-16 and F15E when looking at aircraft lost, since the lines are almost parallel. When a strong interaction exists, the two factor level combination that crosses must be chosen as optimum. Using the same procedure, interaction response tables and plots can be used to analyze all other factor interactions to be studied.

The optimum levels for the four factors can now be selected by choosing the level to minimize or maximize to reach a desired outcome. In the two cases investigated, the minimum Blue aircraft losses are:

A	-1	F18 70%
B	-1	F16 70%
C	-1	F15C 70%
D	1	F15E 100%
With a Y (min) of Blue aircraft lost :Y(Min)=		33.75

Table 8**:** Minimum Blue Loses

The maximum Red Aircraft Destroyed is:

A	1	F18 - 100%
B	-1	F16 -70%
C	-1	F15C -70 %
D	1	F15E -100%

With a Y (max) Red aircraft destroyed:

Y(max)	56.75

Table 9**: Maximum Red Loses**

The Blue losses minimize math model 33.75, which is within the low range (33-34), implying we can minimize F-18, F-16, and F-15C and keep F15 E at full strength. The Red losses maximize math model 56.75, which is within the high range (56-57), implying we can minimize F-16 and F-15C and keep F15 E and F-18 at full strength. The operational analysis is that one can assign F-15C and F-16 units some slack (i.e., a 30% reduction in sorties) in flying one day without major impact to war effort (blend Experiment 10 and 11)

Conclusions

This paper explored whether a qualitatively created ATO can be optimized utilizing design of experiments methods. Given a model that is a valid approximation to expected reality, design of experiments based response surface methods may be used to answer specific questions within the time available to promulgate those answers to fielded forces. Operation Air Power as defined by the ATO produced by the AOC can be quantitatively optimized, resulting in better control of fielded forces. Response surface methods can improve combat air power because the techniques can handle the massive number factors and interactions. RMS is on the cutting edge of current engineering techniques that allow quantitative evaluation of massive amounts of variables and interactions. In a full factorial design, all possible factors and levels are studied simultaneously. Other techniques, such as Fractional Factorial or Central Composite Designs, can be used. As the goal of this paper was to explore if qualitative engineering could be used within an Air Power problem, a full factorial design method was selected. The method was validated; therefore, other techniques could be used and would most likely be more efficient

based on the questions being explored. A secondary goal of using RMS in this paper is to show the potentiality to save lives exposed to risk by the use of quantitative tools. In the real world, it most likely would require a small dedicated team trained in these techniques to study the problem in hand providing a quick overview to make decisions.

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APPENDIX A

Experiment 1			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
77 SQ	1	24 FS	4
94 FS	2	33 FS	6
95 FS	12	42 FS	2
VF 103	4	51 FS	6
VMFA 513	3	52FS	6
		53 FS	6
Total	34	Total	56

Experiment 2			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
522 FS	4	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2

Experiment 2			
Blue Unit	Number Killed	Red Unit	Number Killed
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	39	Total	56

Experiment 3			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	12
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6
Total	35	Total	54

Experiment 4

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	12
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6
Total	35	Total	54

Experiment 5			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
522 FS	4	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6

Experiment 5			
Blue Unit	Number Killed	Red Unit	Number Killed
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	39	Total	56

Experiment 6			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
522 FS	0	24 FS	4
77 SQ	1	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	34	Total	56

Experiment 7			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	5
78 FS	4	22 FS	4

Experiment 7			
Blue Unit	Number Killed	Red Unit	Number Killed
27 FS	4	23 FS	14
522 FS	0	24 FS	4
77 SQ	1	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	34	Total	53

Experiment 8			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	10
522 FS	0	24 FS	4
77 SQ	2	33 FS	6
94 FS	0	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6

Experiment 8			
Blue Unit	Number Killed	Red Unit	Number Killed
Total	33	Total	52

Experiment 9			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
522 FS	0	24 FS	4
77 SQ	1	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	34	Total	56

Experiment 10			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	6	21 FS	9
78 FS	4	22 FS	4

Experiment 10			
Blue Unit	Number Killed	Red Unit	Number Killed
27 FS	4	23 FS	14
522 FS	0	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	35	Total	57

Experiment 11			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
75 FS	2	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	0
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6

Experiment 11			
Blue Unit	Number Killed	Red Unit	Number Killed
Total	35	Total	53

Experiment 12			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
75 FS	0	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	0
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6
Total	33	Total	53

Experiment 13			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	14
75 FS	0	24 FS	4

Experiment 13			
Blue Unit	Number Killed	Red Unit	Number Killed
77 SQ	2	33 FS	6
94 FS	2	42 FS	0
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	31	Total	55

Experiment 14			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	14
75 FS	0	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	0
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	33	Total	55

Experiment 15			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
75 FS	0	24 FS	4
77 SQ	4	33 FS	6
94 FS	2	42 FS	0
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6
Total	35	Total	53

Experiment 16			
Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
75 FS	2	24 FS	4
77 SQ	4	33 FS	6
94 FS	2	42 FS	2

Experiment 16			
Blue Unit	Number Killed	Red Unit	Number Killed
95 FS	10	51 FS	6
VF 103	4	52FS	6
VMFA 513	5	53 FS	6
Total	39	Total	55